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JRC TECHNICAL REPORT

Guidelines for Programme-level Target Setting

Defining Key Performance Indicators, State of the Art and Future Targets

Davies, J.

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Joint Research Centre

EUR 30304 EN

Contact information
Name: Jonathan Davies
Email: jonathan.davies@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

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Definitions of Key Performance Indicators, previously prepared by Michel Honselaar of JRC for the FCH JU have been included in an Annex to the document.

Author

Jonathan Davies.

Abstract

The Fuel Cell and Hydrogen 2 Joint Undertaking (FCH 2 JU) manages the EU funding programme aimed at supporting technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe.

The Multi-Annual Work Programme (MAWP) defines the objectives of the Joint Undertaking over a distinct period and how this Programme is set out to achieve these objectives. As the end of the current MAWP is approaching, JRC has been asked by the Programme Office of the FCH 2 JU to provide a set of guidelines for setting targets for the next MAWP. It is the aim that this work will lead to an improved methodology.

This document provides guidance for selecting and defining Key Performance Indicators (KPI) necessary to evaluate the progress of the Work Programme towards meeting its key objectives. Furthermore, guidance is provided on how to record and evaluate State of the Art data, and methodological tools to arrive at Future Targets. Mostly, the document seeks to give rise to a methodology which is transparent and traceable, allowing for the input of experts and ensuring a well-referenced and organised procedure. A series of draft forms are provided to assist with the recording of KPI, SoA and Future Target data by working groups tasked with the setting of these values.

Whilst the methodology has been developed specifically for the FCH 2 JU MAWP there are many elements which could be applied generically to other work programmes.

1 Introduction

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) was established according to a European Council Regulation as a public/private partnership between the European Commission, European Industry and Research Organisations [1].

It supports research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe and is made up of three members: the European Commission; fuel cell and hydrogen industries represented by Hydrogen Europe; and the research community represented by Hydrogen Europe Research.

The FCH JU has distributed EU funds for projects related to fuel cells and hydrogen, first under Framework Program 7 (FP7) from 2008-2013 and, as the Fuel Cell and Hydrogen 2 Joint Undertaking (FCH 2 JU), under the Horizon 2020 Program (H2020) from 2014 onwards. Note: the organisation will be referred to as FCH 2 JU from now on throughout this document, to avoid confusion.

The FCH 2 JU produces a Multi-Annual Work Programme (hereunder referred to as “the Programme” or MAWP) defining the Objectives of the Joint Undertaking over a distinct period and how that Programme is set out to achieve these Objectives.

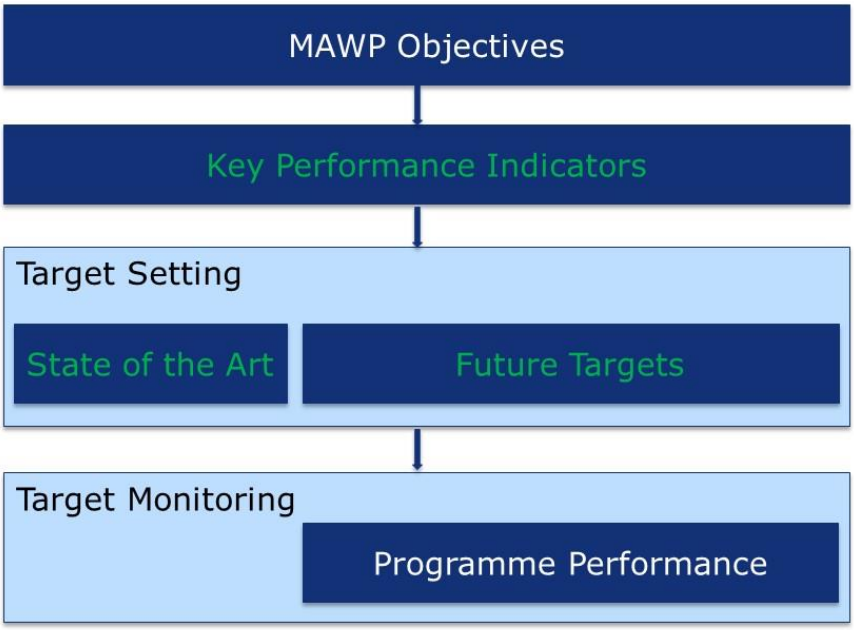
The latest Multi-Annual Work Programme runs from 2014-2020. A 2018 addendum to the MAWP contains the latest summary of Key Performance Indicators, separated according to Technology or Application. A Key Performance Indicator (KPI) is a quantifiable parameter used to evaluate performance, in this instance, the degree of success of the Programme in meeting its strategic objectives. Choosing appropriate high-level MAWP KPIs therefore requires a good understanding of the overall Programme Objectives and the State of the Art (SoA) of hydrogen and fuel cell technologies.

For each Key Performance Indicator, a SoA value was provided in the MAWP for 2012 and 2017 (the values were revised in the 2018 addendum) and a series of Future Target values were provided for 2020, 2024 and 2030.

As the end of the current Multi-Annual Work Programme is approaching, JRC has been asked as part of a Framework Contract between the JRC and the FCH 2 JU, to provide a guideline document for selecting Programme KPIs[1], establishing the SoA, and setting targets for the next MAWP. Figure 1 is a schematic showing the aspects that will be covered in this report (highlighted in green). Programme level KPIs will need to be selected relevant to the objectives of the new MAWP. Revised SoA figures for 2020 will need to be provided for all the identified KPIs, and future targets will need to be set for the coming work programme. Ultimately, the performance of that programme will have to be measured against the degree of achievement of these targets.

[1] Programme Level KPIs may also be supplemented by KPIs at Annual Work Programme (AWP) or project level but these will not be discussed in this document.

Figure 1: Schematic showing the outline of the topics to be discussed in this methodology report.



Source: JRC, 2020.

For comparison, it is interesting to note how other Fuel Cell and Hydrogen research programmes document the setting of targets. The U.S. Department of Energy (DoE) Hydrogen and Fuel Cells Program maintains a Program Records page [2]. This documents the sources behind key numbers and facts that are cited or referenced by the DoE Hydrogen and Fuel Cells Program in its plans, reports, Web pages, announcements, speeches, presentations and news releases. The Program Records explain the inherent assumptions, source data and calculation methodologies used. The decision-making process behind the Fuel Cell and Hydrogen Joint Undertaking target setting process is not publicly documented to this extent.

A useful example from the US DoE program is the US DRIVE Target Explanation Document for On-board Hydrogen Storage for Light Duty Vehicles [3] which gives a detailed breakdown of individual targets, and the assumptions made when defining them. The U.S. DRIVE Partnership is between the DoE, the US Council for Automotive Research (USCAR), energy companies, and utility companies and organisations. The approach underlying the target explanation document is likely not applied uniformly across the different branches of the DoE program, but it is an example of a detailed and well-documented approach to target setting with active involvement of as exhaustive range of stakeholders as possible in the process.

In this report, we propose a series of measures which could be taken to ensure a high quality approach to target setting for the forthcoming Programme.

2 Quality Requirements for KPIs for Monitoring Progress towards Objectives

2.1 SMART-TRACK

In this section, some general considerations are introduced for establishing a methodology for setting Programme targets. The next Multi-Annual Work Programme will have a series of objectives. In business, objectives are frequently defined using the SMART acronym [4] where the objective should be Specific, Measurable, Assignable, Realistic and Time-related[2]. The objectives of the Programme and therefore the associated KPIs that derive from these objectives should comply with SMART criteria.

In addition to the SMART criteria, additional considerations of Transparency, Reliability, Appropriateness and Consistency are also discussed, leading to the use of an additional SMART-TRACK acronym when applying this methodology to KPIs. The way in which each of these terms applies to the methodology of target setting is summarised below.

Specific:

The KPIs used should be specific, i.e. in addition to the required alignment with a given objective of the MAWP they should be clear, well-defined and address specific aspects of a technology or application for improvement.

Measurable:

It is important that all KPIs are quantitative and measurable. i.e. it must be possible to measure, report and monitor the evolution of the KPI as a quantitative value. This necessitates clear identification of boundary conditions that apply for their measurement. Wherever possible, standard reference conditions and test protocols should be applied when measuring KPI values.

Assigned:

In business, this means that someone is assigned with the task of improving on the value for a specific KPI. In the case of the FCH 2 JU Programme, once the KPIs have been defined, the SoA researched and targets set, it is important that the Calls originating from the FCH 2 JU and the projects funded are clearly assigned to achieving these KPI targets during the Multi-Annual Work Programme i.e. that the yearly project calls match the objectives of the work programme and that the proposals submitted to the call include the appropriate type, amount and timing of effort to improve the KPI values.

Realistic:

In this instance, Realistic applies to the targets. Can the KPI target values related to programme objectives, , realistically be expected to be achieved in the timeframe allowed considering the resources available?

[2] Note, there are several different versions of the SMART criteria. In some cases, "A" stands for Achievable or Attainable; "R" may also stand for Relevant. All of these are covered in our extended SMART-TRACK list of criteria via appropriate synonyms.

Time-related:

It is clear from the structure used that KPI targets are set for a given timeframe. However, one further thing to consider is the evolution of the Programme. In general, KPIs, and the associated SoA and target values should be regularly reviewed in order to ensure that the selected KPIs are still the most relevant, and that their associated targets are still appropriate across the whole Multi-Annual Work Programme duration.

Transparent / Traceable:

This is a highly important part of any procedure. In this instance, it is crucial that the process of defining the SoA is well-documented, with the associated references, and that a full explanation is provided regarding how the set of Future Targets have been agreed upon.

Reliable:

A well-informed decision has been taken when selecting the KPI, and a due-diligence process has been undertaken to inform the current SoA i.e., a thorough traceable analysis of the current SoA has been provided, and it is appropriate for the current Technology Readiness Level (TRL) of the technology. This is to ensure relevance and quality of SoA data and future target values, and to avoid values being assigned on an arbitrary basis with insufficient supporting evidence.

Appropriate:

Are the selected KPIs appropriate for the Programme Level? When considered together, do they comprehensively cover the programme objectives without undue overlap and/or mutual interference?

Furthermore, FCH technologies are often co-existing or competing with incumbent technologies. Hence defining KPIs, establishing SoA values and setting targets must consider the related performance of other technologies against this KPI in order to be relevant and appropriate.

Consistent:

Multiple different FCH technologies may be considered for a certain application. Furthermore, several different applications may be addressed by the same technology (e.g. ranges of power outputs of stationary applications). Have the KPIs and targets been consistently defined across these multiple technologies and applications?

2.2 Process

In this document the focus is placed on documenting the process by which KPIs, SoA and targets are determined. In each of the following sections, the factors to be considered when defining KPIs, assigning SoA values and setting targets will be laid out. This will culminate in a series of forms which the JRC proposes should be completed for each KPI.

The forms serve the purpose of a reporting tool. They are based on the assumption that KPIs, SoA and targets will be agreed upon at a Round Table exercise involving all relevant stakeholders and the completed forms would be the consolidated output of that exercise. There are of course many means to collect contributing information from experts (e.g. via Market Survey, literature reviews etc.). However, the JRC does not seek to impose that part of the process through this document. The aim is to provide tools and guidance to ensure the quality and traceability of the input from the experts.

That being said, the forms provided could also be used to source information from experts, however a considerable amount of collation of data would still be required in order to distil the information received.

3 Key Performance Indicators

When defining a Key Performance Indicator, several factors need to be considered. They are given below:

Nature of KPI: Generic/Derived/Specific

In previous work performed by the JRC for the FCH 2 JU [5], a distinction was made between Generic KPIs, Derived KPIs and Specific KPIs.

Generic KPIs are applicable to nearly all technologies (e.g. automotive, auxiliary, stationary, Hydrogen Refuelling Stations (HRS), production) and can therefore be harmonised across technology areas (for example through the use of consistent units or boundary conditions). This allows for comparison within technology areas, across technology areas and among competing technologies which are not based on hydrogen and fuel cells (this should come with the caveat that, even where Generic KPIs have the same definition and units, the technologies may not always be directly comparable, for example if they are at significantly different TRL). Efforts have previously been made by the FCH 2 JU and JRC to standardise Generic KPIs wherever possible.

Examples of Generic KPIs are:

- CAPEX/manufacturing cost
- Efficiency
- Degradation
- Durability
- Lifetime
- Downtime/availability
- Reliability
- Maintenance Cost.

JRC also proposed definitions of Generic KPIs which have been previously used by the FCH 2 JU when defining the MAWP KPIs. A list of definitions are included in Annex A.

In some cases, a number of Generic KPIs can be used to determine a further KPI, which will be referred to here as a Derived KPI. An example of a Derived KPI is the levelised cost of operation (LCoO) for hydrogen fuel cell (sub)systems.

$$LCoO = \frac{SC + OM}{AF * LT * \overline{\overline{AP}}} + \frac{FU}{\overline{\overline{AE}}}$$

where SC represents system cost, OM is Operations and Maintenance cost, AF is the availability factor, LT is lifetime, AP corresponds to the Average Power, FU is the Fuel cost and AE corresponds to the average efficiency.

A more detailed derivation is given in Annex A.

Specific KPIs apply only for individual technologies or applications (see below). Some examples of Specific KPIs are:

- Power density, energy density, current density
- Gravimetric capacity, volumetric capacity
- Start-up time, cold start capabilities, warm start capabilities
- Freeze operation temperature
- Operating range
- Number of start-stops; transient response
- Footprint, weight, volume
- Standby power consumption
- Application cost, installation cost

Some harmonisation across relevant technology areas is still possible. Again, some example definitions are provided in Annex A.

3.1 Considerations when defining KPIs

Name:

Be consistent in the naming of KPIs. In the case of Generic KPIs, the use of consistent naming across technology areas should be followed.

Unit:

As both SoA and target values are numbers, the selection of the unit and its consistent use is critical to allow for comparison between SoA, target values and project results; using units which are the most common in the field is advised. Additionally, relative units should be used wherever possible (e.g. Euro/kW, Euro/km, MJ/kg etc.).

Particular attention should also be paid towards the calculation and reporting of efficiency values to ensure that Higher Heating Value (HHV) or Lower Heating Value (LHV) are being stated clearly and used consistently. Furthermore, for cost-related KPIs, clear specification of the cost origin (e.g. CAPEX, O&M, the use of a specific fuel etc.) should be given. In the case of CAPEX, the corresponding manufacturing volume should be provided.

Definition:

To be useful, the KPI must be clearly defined. Again, the use of common definitions in the case of Generic KPIs should be encouraged.

Technology / Application:

Is the KPI technology-specific, or is it application-specific (or both)? In general, it would be expected that lower TRL technologies would be more likely to have technology-based KPIs, whereas high TRL technologies would have application-based KPIs (and also to have deployment targets).[3]

Example:

The electrolyser targets in the MAWP addendum of 2018 [6] are divided along technology lines , with separate tables for alkaline electrolysers (AEL), Proton Exchange Membrane electrolysers (PEMEL) and Solid Oxide electrolysers (SOEL). This is appropriate because the three technologies are at different stages of development (TRL levels) and the challenges facing each are quite different.

By contrast, the Stationary Fuel Cell targets are based on the power output of the technology, i.e. the application. There are three different tables of MAWP targets consisting of:

- residential micro CHP for single family homes and small buildings (0.3 - 5 kW)
- commercial and larger buildings (5 - 400 kW)
- converting hydrogen and renewable methane into power in various applications (0.4 - 30 MW)

Whilst the technology is not stated in these tables, it is still likely that these figures refer to specific technologies being covered by the FCH 2 JU projects (Proton Exchange Membrane Fuel Cells (PEMFC) and Solid Oxide Fuel Cells (SOFC)). In particular, for large-scale applications it is unclear whether other fuel cell technologies such as Phosphoric Acid Fuel Cells (PAFC) and Molten Carbonate Fuel Cells (MCFC) have been included in the SoA assessment, despite their widespread global use. Therefore, it is possible that these tables are restricted both by application and by technology and this should be clearly stated.

Granularity:

At what scale does the KPI apply? For example, in the case of KPIs relating to electrolysers, KPIs were specified at Generic System (technology independent); Specific System (technology dependent) and Stack level. Furthermore, where terms such as system, installation, module, unit etc. are used, the differences in the components and balance of plant (BoP) included at each level of granularity should be defined.

Single Value / Range:

Should the KPI have a specific value, or is a range of values more appropriate? In general, if the aim is to try to reach a target, a single value is likely to be required, however there are specific occasions where a range of performance is necessary. In that case, what do the minimum and maximum values correspond to? It may be that a range of values are deemed acceptable for achieving the target, or alternatively that the range in the target corresponds to, for example, a range of power scale of the technology being considered. This should be clearly stated.

[3] It could be considered to associate a TRL level with each KPI, although it would depend on the nature of the KPI as to whether this is possible or not. However, the author would advise against putting a TRL threshold on the submission of data as this may limit the amount of data submitted and omit important information.

Example:

In the case of the Stationary Fuel Cell targets for MAWP 2014-2020 there are several cases where ranges have been used for KPI values (both the SoA and targets). These have not always been used consistently across the different power scales, and the reasoning behind the ranges is unclear.

In the case of CAPEX, a single value is provided for micro-CHP whereas a range of CAPEX is provided for mid-sized and large-scale applications (see Table 1). This makes sense if it is considered that the cost per kW is likely to vary with manufacturing scale. The lower target value is possibly the limit at the higher size; however, this should be clearly indicated. However, if this is the reasoning behind the choice of a range, then in principle the ranges should be continuous when all sizes are considered together, which is not the case.

Table 1: CAPEX State of the Art and FCH 2 JU targets for different scales of Stationary Fuel Cell technologies

Technology	**Scale**	**Parameter**	**Unit**	**State of the Art**		**FCH 2 JU Target**		
				2012	**2017**	**2020**	**2024**	**2030**
Micro-CHP	0.3-5 kW	CAPEX	EUR/kW	16,000	13,000	10,000	5,500	3,500
Mid-size	5-400 kW			6,000 - 10,000	5,000 - 8,500	4.500 - 7.500	3.500 - 6.500	1,500 - 4,000
Large-scale	0.4-30 MW			3,000 - 4,000	3,000 - 3,500	2,000 - 3,000	1.500 - 2.500	1,200 - 1,750

Source: JRC (2020), adapted from the Addendum to the MAWP of the FCH JU (2018)

For these stationary applications there are other inconsistencies in the use of ranges. For example, the Lifetime target is a single value for micro-CHP and large-scale applications, but a range is given for the mid-scale (see Table 2). The reasoning for this is unclear. Similar inconsistencies are observed for the durability of the stack and efficiency values.

Table 2: Lifetime State of the Art and FCH 2 JU targets for different scales of Stationary Fuel Cell technologies

Technology	**Scale**	**Parameter**	**Unit**	**State of the Art**		**FCH 2 JU Target**		
				2012	**2017**	**2020**	**2024**	**2030**
Micro-CHP	0.3-5 kW	Lifetime	Years	10	12	13	14	15
Mid-size	5-400 kW			2-20	6-20	8-20	8-20	15-20
Large-scale	0.4-30 MW			n/a	15	25	25	25

Source: JRC (2020), adapted from the MAWP of the FCH 2 JU (2018)

Boundary Conditions:

It is vital to clearly state the boundary conditions that apply when determining the values of the SoA and target(s) associated with a given KPI. These should be defined to be as close as possible to the intended application conditions and be as specific as possible.

However, the more specific the boundary conditions, the less flexible the KPI will be to compare data from different projects obtained under slightly different conditions (particularly across a range of TRL levels). For higher TRL projects, wherever possible harmonised data should be produced using relevant harmonised testing procedures. If the technology or application involved have Factory Acceptance Test (FAT) or Site Acceptance Test (SAT) procedures then these should be used to help define the boundary conditions for the corresponding KPIs. In general, where there are specific Reference Conditions and Testing Protocols agreed at a European or International level, these should be applied.

Direct measurement / Extrapolated:

Should the actual value measured be reported or can the value be extrapolated from data obtained over a shorter time frame? [4]

Example:

Degradation rates are often given as a value of %/1000 hours. How many hours of testing is necessary to give a reliable value. Can a value be extrapolated from 500 hours testing or is e.g. 5000 hours testing necessary to give a reliable degradation rate? Lifetime (in years) is also unlikely to have been measured directly, so this would need to be an extrapolated value.

A further example, where extrapolation could be useful in the future is regarding targets for manufacturing, where costs and other parameters need to be estimated at scale.

When applied, the method used for extrapolation should be justified and uncertainties on the extrapolated values included.

[4] Values defined as "Direct measurements" should include values that are calculated from direct measurements.

Confidentiality:

Can it be determined from the outset whether project values of the KPI are likely to be Public, Confidential (only shared with the FCH 2 JU) or Commercially Sensitive (not possible to share with the FCH 2 JU)? In the latter case, the KPI would not be an appropriate Programme KPI as it would no longer be ***measurable*** or ***transparent***.

Linked:

Are certain KPIs linked to other KPIs? Is improvement in a particular KPI only of benefit if there is an improved performance in (or no deleterious effect upon) a linked KPI? There is a need to identify up front which KPIs cannot be considered independently.

It is important to ensure that performance is being described in the correct way and that incentives are not driving the improvement of one important KPI at the expense of another.

Example:

An example of this is platinum group metal (PGM) loading in Proton Exchange Membrane electrolysers (mg/W). Whilst a reduction in PGM is desirable, this cannot come at any considerable expense to the current density, efficiency or degradation rate of the electrolyser. Therefore, values presented for any individual KPI may be misleading if the others are not presented simultaneously e.g. where a low PGM loading is used, but degradation rates are high.

Figure 2: Form to be Completed for each Key Performance Indicator

MAWP Key Performance Indicator

Name:	***Unit:***
Type:	Generic/Derived/Specific
Technology (and Granularity e.g. System/Module/Stack):	
Application:	
Single value / Range: *If range then conditions at max/min values:*	Single value / Range
Definition:	
Boundary Conditions:	
Direct measurement / Extrapolated:	(Direct/Extrapolated)
Confidentiality:	(Public/Confidential/Commercially Sensitive)
Linked to:	
Reasoning:	

4 State of the Art

For the SoA for each KPI, along with the ***Name***, ***Unit*** (of the KPI) and ***Year*** (of the SoA value) we propose that the following is provided:

Geographical Location:

Does the SoA value represent the Global or European SoA? The geographical location can be provided more specifically with the source (see below).

Sources:

As with any scientific data, it is important that SoA values are well-referenced, traceable and transparent. With that in mind it is important that the source data behind any SoA values are documented. In terms of ***Reliability*** of the sources, a larger number of well-referenced sources will provide a more reliable value of the SoA. In general, the ***Method*** used to define the value for the SoA should be to pick out the Best in Class, however, there may be a circumstance where a number of values can be averaged to provide a SoA value (i.e. a number of values from sources not deemed particularly reliable individually, but where there are a significant number of similar values).

It is also important to define what is meant by the SoA. Depending on the TRL of the technology under consideration the SoA could be from Research (e.g. academic), Technology Validation or Demonstration, or from a Commercial product. This should be recorded with the Reference Source. Along with the source, an estimated TRL value, or TRL range, for the SoA source could be provided. If this is difficult to assess, the following ranges could be used: Research / Proof of Concept: TRL 1-3; Technology Validation: TRL 4-6; Demonstration: TRL 7-9; Commercial (beyond TRL 9)).

In certain cases, it may not be possible to provide the source of the SoA for a KPI, especially if the SoA is from a commercial company. Therefore, it should be recorded whether the SoA value originates from a Public or Private Source, and in the rare case where it cannot be substantiated with a reference document, that it is the SoA according to Expert Opinion.

Additionally, where relevant the SoA of the current incumbent technology can be provided. This is particularly useful to consider when agreeing on future targets that will be necessary for an emerging technology to achieve.

Reliability:

There are certain methods available for defining the ***Reliability*** of the SoA value. An example is the NUSAP method [7], which uses five qualifiers: Numeral, Unit, Spread, Assessment and Pedigree for establishing a numerical assessment of the quality of SoA data.. Whilst the JRC does not recommend any particular method for defining reliability, we would advise that a scoring method of some sort is incorporated.

Under the NUSAP method the Numerical qualifier is based on expert judgement. The Unit qualifier is the unit of the numeral and the numerals are given with Spreads (i.e. a high and low estimate). The Assessment qualifier is a judgement based on the quality of the data and the Pedigree matrix guides the expert in the assessment of the data quality [8]. The matrix (see Table 3) relies on a systematic approach to provide a quantitative score base on qualitative expert judgement of three criteria: Convergence of data, Empirical Basis and Quality of Reports. These can be scored 0-4 according to the table. These three numbers are then averaged and based on the result, a “low”, “medium” or “high” quality estimate for reliability can be given where “low” < 2.0, “medium” = 2.0-2.5 and “high” > 2.5.

Table 3: Pedigree matrix, from Energy Technology Reference Indicator projections for 2010 -2050, J. Carlson, EUR 26950 EN, 2014 [8].

	Convergence of data	**Empirical Basis**	**Quality of Reports**
Criteria Score	*Distribution of data*	*Availability of data sources*	*Type of sources*
4	Very strong agreement (standard deviation / median <5 %)	Ample choice of data (>10 sources)	All excellent reports
3	Strong agreement (standard deviation / median <8 %)	Satisfactory choice of data (5 - 10 sources)	Majority excellent reports
2	OK agreement (standard deviation / median <12 %)	Small sample of data available (2 - 5 sources)	Half excellent reports
1	Weak agreement (standard deviation / median <20 %)	Single source	Minority excellent reports
0	No agreement	Educated guess	No excellent reports

As mentioned above, this is one method of arriving at a score for the reliability of SoA data. We would suggest that a method is chosen that is appropriate for the process by which the assessment is made (i.e. appropriate for the resources/time available for performing the assessment).

In Figure 3 a draft form is provided that could be used as a guideline for submitting SoA reference data for each KPI.

Figure 3: Form to be completed with SoA for each Key Performance Indicator

State of the Art

KPI Name:

Year: ***Value:*** ***Unit:***

Geographical Coverage: Global/EU

No. of sources: ***Method:*** Average / Best in Class

SoA of technology:

Source	Value	Unit	Level/TRL	Reference		
Public			Academic			
Private			Prototype			
Expert			Commercial			

SoA of incumbent technology (where appropriate):

Source	Value	Unit	Level/TRL	Reference		
Public			Academic			
Private			Prototype			
Expert			Commercial			

Reasoning:

5 Future Targets

When defining future targets there are two major factors to consider. Firstly, the Purpose behind defining the target, and secondly the Methodology and Reasoning used to come to the target values. It should be noted that JRC is not recommending or seeking to impose a particular methodology. There may be different scenarios where the FCH 2 JU consider a particular methodology more appropriate. However, the reasoning behind arriving at a specific target value should be clear and transparent.

Purpose:

In this instance, what is meant by the purpose of a KPI target? There are multiple different motivations for target setting.

Driver: to encourage better performance. The final value required may not be known but the direction of travel is important in improving the possibility of a breakthrough for a technology.

Feasibility: given the resources and time available, what target is achievable? This may not be a necessary final value to achieve any overall programme goal.

Requirement: it is known that in order to achieve a necessary performance or to achieve a market breakthrough, a certain value of a KPI is required. These requirements may include, the ability to compete with an incumbent technology or with international competition in the same technology. There may also be a need to comply with legislation.

In the shorter term, targets are more likely to be drivers. In the longer term, the target value should have some relevance to the commercialisation and deployment of a technology for a certain application. However, it is not necessarily the case that all the “purposes” mentioned above will be taken up by the FCH 2 JU.

Methodology:

There are different methodologies that can be used in order to provide targets associated to a KPI for a given technology. They are:

Detailed studies: these are bottom up calculations, simulations or modelling based on (for example) individual components. This could include cost calculations based on price of materials, labour etc. This approach is likely to be the most effort-intensive but most accurate approach.

Learning Curve: using past data to predict future performance. This requires reliable historical data in order to be able to accurately predict future trends. The term “learning curve” is typically used to characterise cost evolution, not technical performance parameters. However, an equivalent process of learning from experience and extrapolating from existing data can be applied to technical parameters.

Market Survey: using expert solicitation to provide forecasts. This can be speculative as it depends on the opinion of an individual (or group of individuals) and is likely to be the quickest but the least accurate of the three methods.

It is important to state the source behind the methodology e.g. to reference any source work that has led to the targets, or to identify the expert (or panel of experts) that has provided the target value.

In Figure 4 a form is provided that could be used as a guideline for submitting Target Values for each KPI.

Figure 4: Form to be completed with Future Targets for each KPI

Future Targets

KPI Name:	*Unit:*

Year	*Target Value:*	*Purpose*	*Method Used*
		Driver	Model/Calculation
		Feasible	Learning Curve
		Requirement	Market Survey

Reasoning:

Reference Type	*Reference*	*Year*
Journal Article		
Public Report		
Other public document		
Private document		
Expert Opinion	(give name)	

The three forms given in this document should be accompanied by a Master Sheet with a list of KPIs (per topic), and whether the associated SoA and targets have been provided satisfactorily with the appropriate documentation (as shown in Figure 5.

Figure 5: Master Sheet for tracking submission of KPI documentation.

Master Sheet

Topic	***KPI (and unit)***	***SoA***	***Target 1***	***Target 2***	***Target 3***
Topic 1	KPI 1	✓	✓	✓	✓
	KPI 2	✓			
	KPI 3				
	KPI 4				
Topic 2					

6 Monitoring and Evolution

In general, targets should not be considered as a static creation. KPIs, the SoA and Targets should be reviewed at regular intervals and where deemed no longer appropriate, adjusted and updated.

The method of review will vary according to whether a Target, SoA or KPI is being considered.

KPI: As the Programme progresses, it may be important to reassess from time to time whether the KPIs are still the most appropriate and whether they are being addressed via the Programme calls. Are the correct performance improvements being incentivised by the KPIs that have been set? Every year projects funded under the FCH 2 JU are required to submit KPI data to the TRUST (Technology Reporting Using Structured Templates) database. The Programme level KPIs are easily identifiable via TRUST, so it should be easy to determine from TRUST submissions whether they are being addressed by the ongoing projects.

SoA: As mentioned above, TRUST can be used to monitor on a yearly basis whether any FCH 2 JU projects have improved on the existing SoA. We would propose that values submitted to TRUST which improve on the SoA trigger a review. This would mean a more detailed inspection of the achieved value (for example: is it a one-off achievement that needs further validation?; at what TRL level has the SoA been improved upon?). Assuming this review confirms that the target has been consistently achieved at a relevant TRL level to the existing SoA, it could be proposed to update the SoA. This could be embodied in regular reviews. Secondly, the Programme may become aware of global advancements in the SoA, achieved by actors outside of the FCH 2 JU funded projects. In this instance, again a regular SoA update should be factored into the Programme.

Target: As for the SoA, we would propose that the achievement of a Programme KPI target should also trigger a review, as outlined above. Assuming the review confirms that the target has been consistently achieved at a relevant TRL level to the existing SoA, it could also be proposed to change the Programme KPI targets accordingly at a regular interval throughout the Programme.

We would propose that the above checks be made on a yearly basis, but that any formal update of the SoA and target values takes place less frequently (every 2 or 3 years) to allow time for verification of the values achieved.

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List of abbreviations and definitions

AEL	Alkaline Electrolyser
BoP	Balance of Plant
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
DoE	Department of Energy (of the US)
EU	European Union
FAT	Factory Acceptance Test
FC	Fuel Cell
FCH (2) JU	Fuel Cell and Hydrogen (2) Joint Undertaking
FP7	Framework Programme 7
H2FC	Hydrogen Fuel Cell
H2020	Horizon 2020
HHV	Higher Heating Value
HRS	Hydrogen Refuelling Station
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCoO	Levelised Cost of Operation
LHV	Lower Heating Value
MAWP	Multi-Annual Work Programme
MCFC	Molten Carbonate Fuel Cell
NUSAP	Number, Unit, Spread, Assessment, Pedigree
O&M	Operating and Maintenance
PAFC	Phosphoric Acid Fuel Cell
PEMEL	Proton Exchange Membrane Electrolyser
PEMFC	Proton Exchange Membrane Fuel Cell
PGM	Platinum Group Metals
RTD	Research, Technology Development and Demonstration
SAT	Site Acceptance Test
SMART	Specific, Measureable, Assigned, Realistic, Time-Related
SMART-TRACK	Specific, Measureable, Assigned, Realistic, Time-Related, Transparent, Reliable, Appropriate, Consistent, KPIs
SoA	State of (the) Art
SOEL	Solid Oxide Electrolyser

SOFC	Solid Oxide Fuel Cell
TMA	Technology Monitoring and Assessment
TRL	Technology Readiness Level
TRUST	Technology Reporting Using Structured Templates)
US	United States of America

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Annexes

Annex 1. Definitions and Examples of commonly used Generic, Derived and Specific KPIs

Generic KPIs

Definitions of Generic KPIs as prepared in [9]:

Efficiency:

Ratio of the sum of the energy contained in the outputs of the system to the sum of the energy contained in the inputs of the system

To be defined per technology (area):

- Inputs: e.g. regulated alternating current, direct current, hydrogen, fuel (LHV), heat

- Outputs: e.g. regulated alternating current, direct current, hydrogen, fuel, useful heat (LHV)

Conditions/characteristics to be specified per technology (area), when necessary, under which the KPI is being evaluated/assessed:

e.g. operating conditions (e.g. temperature), outputs (e.g. quality, pressure), operating point (e.g. rated capacity)

Degradation:

Relative percentage of voltage, current, power, efficiency (LHV), production capacity, etc. loss per 1000 operation hours under realistic operational profiles and, when appropriate, after having applied a rejuvenation procedure.

The measurement data that is used to determine the loss should be obtained using (near) equal operating conditions.

Conditions/characteristics to be specified per technology (area), when necessary, under which the KPI is being evaluated/assessed:

E.g. Operating profile (e.g. duty cycles, transient operation, start-up, shut-down), technical characteristics (e.g. catalyst loading), operating conditions (e.g. temperature), inputs (e.g. quality), outputs (e.g. quality, pressure), operating point (e.g. rated capacity)

Note: Absolute percentage loss is to be avoided as it will not enable comparison among technologies

Durability:

Time that a maintained system, without its major components/parts being replaced, is able to operate until an End-of-Life criterion is met

To be defined per technology (area):

- End-of-Life criterion: E.g. percentage of voltage, current, power, efficiency (LHV), production capacity (etc.) loss

- Conditions/characteristics to be specified per technology (area), when necessary, under which the KPI is being evaluated/assessed:

E.g. operating profile (e.g. duty cycles, transient operation, start-up, shut-down), operating conditions (e.g. temperature), inputs (e.g. quality), outputs (e.g. quality, pressure), operating point (e.g. rated capacity), technical characteristics (e.g. catalyst loading)

Lifetime:

Time that a maintained system, with its major components/parts being replaced (when necessary), is able to operate until an End-of-Life criterion is met

To be defined per technology (area):

- End-of-Life criterion : E.g. percentage of voltage, current, power, efficiency, production capacity (etc.) loss
- Conditions/characteristics to be specified per technology (area), when necessary, under which the KPI is being evaluated/assessed: E.g. operating profile (e.g. duty cycles, transient operation, start-up, shut-down), technical characteristics (e.g. catalyst loading), Operating conditions (e.g. temperature), inputs (e.g. quality), outputs (e.g. quality, pressure), operating point (e.g. rated capacity)

Note: When major components/parts do not need to be replaced, then the lifetime of the system is the same as the durability

Downtime (or availability):

Downtime:

Time that the system is not able to operate and includes time for (un)scheduled maintenance, repairs, overhaul, etc.

Or

Availability:

Ratio of the time that the system was operational/able to operate minus the downtime of the system to the time that the system was expected to operate. Downtime is the time that the system is not able to operate and includes time for (un)scheduled maintenance, repairs, overhaul, etc.

Note: Having downtime as a KPI is preferred.

Reliability:

Mean time between failure (or stoppage) of the system that render the system inoperable without maintenance

Specific cost – (sub) system:

Ratio of the cost of manufacturing (labour, materials, utilities, etc.) of the system at current and up-scaled production levels (exclude monetary costs, e.g. overheads, VAT, taxes, insurances and other taxes) to the capacity of the system at rated capacity.

System boundaries are similar to the system boundaries considered for the efficiency determination.

Specific maintenance cost:

Ratio of the maintenance costs (both fixed and variable)(including: overhaul cost, repair cost, replacement cost, maintenance cost; labour costs; etc.) per unit of energy output

To be defined per technology (area):

- Energy output: E.g. electricity, hydrogen

Note: Either individually cost of spare parts and man-hours or selecting a fixed labour rate (€/h)

Derived KPIs

An example of a derived KPI is given in below:

Levelised cost for H2FC (sub)systems: generic KPIs as determinants for a Derived KPI:

$$LCoO = \frac{SC + OM}{AF * LT * \overline{AP}} + \frac{\mathrm{FU}}{\overline{\overline{AE}}}$$

$$AF = \frac{OT - DT}{OT}$$

$$AP = \frac{PW(@BG) + PW(@DU) * (1 - (PD * DU))}{2}$$

$$AE = \frac{EF\ (@BG) + EF\ (@DU) * (1 - (ED * DU))}{2}$$

SC	**- System Costs**
OM	**- Operations and Maintenance Costs**
AF	**- Availability Factor**
LT	**- Lifetime**
AP	- Average Power
FU	- Fuel cost
AE	- Average Efficiency
OT	- Operating Time
DT	**- Downtime**
PW	- Power
BG	- Beginning of Operation
PD	**- Power Degradation**
DU	**- Durability**
EF	**- Efficiency**
ED	**- Efficiency degradation**

Technology or application specific KPIs

Proposal for definitions as prepared in [9]

Application Costs:

Cost of manufacturing (labour, materials, utilities, etc.) the application at current production levels (exclude monetary costs, e.g. overheads, VAT, taxes, insurances and other taxes). System boundaries are similar to the system boundaries considered for the efficiency determination.

Specific Installation Costs:

Cost related to installing (site and connect) the system to the application

Start-up time:

Time required to reach 100% output when starting the device from stand-by mode (system already at operating temperature and pressure)

To be defined:

- *Output: E.g. rated capacity, hydrogen production capacity*

Transient response:

Ratio of the increase in power from minimum part load to rated capacity to the time required to achieve the increase in power

To be defined:

- *Minimum part load: percentage of rated capacity*

Cold start:

Time required to reach 100% output at - 20C ambient temperature

To be defined:

- *Output: E.g. rated capacity, hydrogen production capacity*

Warm start:

Time required to reach 100% output at + 20C ambient temperature

To be defined:

- *Output: E.g. rated capacity, hydrogen production capacity*

Gravimetric capacity:

Ratio of the weight of the usable amount of hydrogen stored in the compressed hydrogen storage system to the total weight of the compressed hydrogen storage system.

The total weight of the compressed hydrogen storage system includes total weight of stored hydrogen, tank(s), BoP components and auxiliary system components).

Volumetric capacity:

Ratio of the weight of the usable amount of stored hydrogen in the compressed hydrogen storage system to the total volume of the compressed hydrogen storage system.

The total volume of the compressed hydrogen storage system includes total volume of stored hydrogen, tank(s), BoP components and auxiliary system components)).

Specific power:

Ratio of the power at rated capacity to the weight of the system

Power density:

Ratio of the power at rated capacity to the volume of the system

Standby power consumption ratio:

Ratio of power usage of the auxiliary equipment when the system is idling to the rated capacity of the system

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